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WILLIAM C. LINDSEY

and

YOUNG M. KIM

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on

SYSTEM FOR, AND METHOD OF, TRANSMITTING DATA FROM A TRANSMITTER TO A RECEIVER AND RECOVERING THE DATA AT THE RECEIVER

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Attorneys
FULWIDER PATTON LEE & UTECHT, LLP
HOWARD HUGHES CENTER
6060 Center Drive, Tenth Floor
Los Angeles, California 90045

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This invention relates to systems for, and methods of, transmitting data from a transmitter to a receiver. The systems and methods of this invention provide for a transmission and reception of data with a greater accuracy than the systems and methods of the prior art.

BACKGROUND OF A PREFERRED EMBODIMENT OF THE INVENTION

In systems now in use, digital data is transmitted from a transmitter to a receiver. The digital data received at the receiver is not easily recognized. This results in part from noise produced in the transmission of the data from the transmitter to the receiver. It also results in part from the fact that the digital data travels in different paths from the transmitter to the receiver. For example, the digital data preferably travels directly from the transmitter to the receiver. However, the digital data can also travel from the transmitter to positions misaligned with the transmitter and the receiver and then travel from the misaligned positions to the receiver.

This misalignment causes the data received at the receiver from the misaligned position to be out of phase with the signals passing directly from the transmitter to the receiver. This out-of-phase relationship makes it difficult to recover the data at the receiver. The problem is aggravated because the receiver can often receive the same data from a number of different misaligned positions in addition to the data passing directly from the transmitter to the receiver. The misalignment can cause the data transmitted from the transmitter to the receiver to fade

because the phases of the misaligned signals are such that the amplitudes of the misaligned signals are subtracted from the amplitude of the signals translated directly from the transmitter to the receiver.

Attempts have been made to alleviate the problems of recovering data at the receiver when the data has been blurred by noise and by misalignments in phase. For example, in systems now in use for sending digital data from a controlled station (e.g., a transmitting station) to a controlling station (e.g., a receiving station), the digital data is provided with repetitive sequences of M modulations where M is a constant. Each of the M data modulations in each sequence is different from the other ones of the M modulations in the sequence. The M data modulations at the transmitter are provided in accordance with instructions from the controlling station (e.g. receiver). The modulated data is transmitted from the transmitter to the receiver in packets. In a first packet or sequence of packets, the data may be modulated with a first one of the M data modulations. In a second packet or sequence of packets, the data may be transmitted with a second one of the M data modulations. In a third one of the packets or sequence of packets, the data may be transmitted with a third one of the M data modulations.

In other systems now in use, the digital data in each packet or sequence of packets may be transmitted from the transmitter to the receiver at individual ones of N spreading codes. For example, the modulated data in a first one of the packets or sequence of packets may be

transmitted from the transmitter to the receiver at a first one of the N different spreading codes. The data in a second one of the packets or sequence of packets may then be transmitted from the transmitter to the receiver at a second one of the N spreading codes rates. The data in a third one of the packets or sequence of packets may be subsequently transmitted from the transmitter to the receiver at a third one of the N spreading codes. Each spreading code may provide for a transmission of the data at a different rate. The N different spreading codes may be provided in accordance with instructions from the receiver.

The systems now in use and discussed in the previous paragraphs have reduced the problem of recovering data at a receiver, but have not solved the problem. It is still difficult to recover data at a receiver because of the proliferation in the reception at the receiver of out-of-phase data which clouds the reception and recovery of the in-phase data.

Several documents can be considered as prior art to the invention disclosed and claimed in this application. These are as follows:

(a) U.S. Patent 5,541,955 issued on July 30, 1996, to Jacobsmeyer for an Adaptive Data Rate Modem;

(b) An article published on pages 927-946 of the May, 1998, issue of IEEE Transaction on Information Theory. This article was written by Giusepper Caire et al and was entitled "Bit-Interleaved Coded Modulation";

(c) An article published on pages 54-64 of the January, 2000, issue of IEEE Communications magazine. This article was written by Sanjiv Nanda et al and was entitled "Adaption Techniques in Wireless Packet Data Services";

(d) An article published on pages 2223-2230 of the July, 1995, issue of IEEE Transactions on Communications. This article was written by W. Webb and R. Steel and was entitled "Variable Rate QAM for Mobile Radio"; and

(e) An article published on pages 1218-1230 in the October, 1997, issue of IEEE Transactions on Communications. This article was written by A. Goldsmith and S. Chaa and was entitled "Variable-Rate Variable-Power MQAM for Fading Channels".

The prior art references specified above in paragraphs (a) through (e) disclose systems for modulating data and also disclose systems for providing spreading codes. However, they do not disclose systems for providing a combination of data modulations and spreading codes. They further do not disclose systems which provide channel encodings with either data modulations or spreading codes or both data modulations and spreading codes. There is also no disclosure in the prior art specified above of particular techniques of combining data modulations and spreading

codes to provide an optimal detection of the data even when the data is obscured by considerable amounts of multi-path fading.

BRIEF DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

Data at a transmitter is modulated, in accordance with instructions from a receiver, to provide M different modulations in successive sequences. N spreading codes are also provided in successive sequences at the transmitter, in accordance with instructions from the receiver, alternately with the M data modulations. The alternate sequences of the M data modulations and the N spreading codes are paired and individual ones of the M data modulations and the N spread codes in the paired sequences are combined (e.g. multiplied).

Alternatively, an individual one of the M data modulations is combined (e.g. multiplied) with an individual one of the N spreading codes in the adjacent sequence. The modulator and the spreader may be included at the transmitter with (a) a channel encoder which provides channel coding in accordance with instructions from the receiver, (b) a puncturer which removes particular data in accordance with instructions from the receiver and (c) an interleaver.

The paired combinations of the individual ones of the M data modulations and the spreading codes are transmitted to the receiver, which uses correlation or matched filter

techniques to recover each combination of the individual one of the data modulations and the individual one of the spreading codes. The recovered data is de-spread in accordance with instructions from the receiver, demodulated in accordance with instructions from the receiver and de-interleaved. The particular data punctured from the sequence is re-inserted and the data is then decoded in accordance with the instructions from the receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

Figure 1 is a schematic circuit diagram, primarily in block form, of one preferred embodiment of the invention for transmitting data in a particular format to a receiver;

Figure 2 is a schematic circuit diagram, primarily in block form, of another preferred embodiment of the invention for transmitting data in another format to a receiver;

Figure 3 is a schematic circuit diagram, primarily in block form, of a third preferred embodiment of the invention for transmitting data in still another format to a receiver, this preferred embodiment having advantages over the embodiment shown in Figures 1 and 2;

Figure 4 is a circuit diagram, primarily in block form, of a system constituting a preferred embodiment of the invention for receiving the data in the novel format from the transmitter shown in any of Figures 1-3 and for recovering the data;

Figure 5 is a circuit diagram, primarily in block form, of a system constituting another preferred embodiment of the invention for receiving the data in the novel format from the transmitter shown in any of Figures 1-3 and for recovering the data;

Figure 6 is a circuit diagram of an expanded system constituting a preferred embodiment of the invention, and preferably incorporating any of the systems shown in Figures 1-3, for transmitting data in any of the novel formats of Figures 1-3 to the receiver; and

Figure 7 is a circuit diagram of an expanded system constituting a preferred embodiment of the invention, and preferably incorporating either of the systems shown in Figures 4 and 5, for receiving the data in the novel format from the transmitter shown in Figure 6 and for recovering the data.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENTS OF THE INVENTION

Figure 1 schematically illustrates a system, primarily in block form and constituting a preferred embodiment of the invention, for sending data in digital form in a particular format from a transmitter (generally indicated at 10) to a receiver. The transmitter 10 includes a bus 12 for providing data input in a binary form. A channel encoder 14 may convert each binary signal to a number of binary bits indicating the different channels in which the data is provided. The inclusion of the channel encoder 14 is preferable but not mandatory.

The binary signals in the channel encoder 14 are introduced to a mapper 16. The mapper 16 provides binary indications identifying each of the channels. For example, the paired binary indications 01 could represent an upper right quadrant. Alternatively, the paired binary indications 01 could represent a lower left quadrant. The inclusion of the mapper 16 is preferable but is not mandatory.

The signals from the mapper 16 are modulated by a modulator 18. The modulations may be in a number of different forms each known in the prior art. For example, the modulations may be in the form of quadrature amplitude modulation (QAM), quadrature phase shift keying (QPSK) or star quadrature amplitude modulations (SQAM). The QAM modulations may

illustratively be in 16QAM (where four (4) positions are provided in each of four (4) quadrants) or in 64 QAM (where sixteen (16) positions are provided in each of the four (4) quadrants.

A plurality of different modulations (e.g, M) are provided by the modulator 18. The M different modulations are produced respectively on a sequential basis of successive packets of digital signals. For example, a first modulation may be produced in a first packet or in a successive number of packets. A second modulation may then be produced in a second packet or in a successive number of packets. Successive modulations may be sequentially produced in successive packets, or successive numbers of packets, until the M different modulations are produced. Thereafter, the cycle of M successive modulations is repeated for the packets in successive sequences on a repetitive basis.

The signals from the bus 12, the channel encoder 14, the mapper 16 and the modulator 18 are in serial form. They are converted to a parallel form by a serial-to-parallel converter 20 in a manner well known in the prior art. The parallel signals from the converter 20 are introduced to a plurality of multiplier stages respectively designated as 22a, 22b...22n. Each of the multipliers 22a, 22b...22n also respectively receives an individual one of a plurality of N spreading code signals on an individual one of lines 24a, 24b...24n.

Each of the N spreading codes respectively provided on an individual one of the lines 24a...24n may be produced at a different rate from the rate produced by the other ones of the N spreading codes. Thus, the multiplier 22a may multiply the modulated data $S_1(t)$ and the spreading code C_1 (t) where S_1 represents the first one of the M different data modulations and $C_1(t)$ represents the first one of the N spreading codes. Similarly, the multiplier 22b may multiply the modulated data $S_2(t)$ and the spreading code $C_2(t)$. An adder 26 receives the outputs from the multipliers 22a, 22b...22n. An amplifier may be included in the adder 26.

The data modulations $S_1(t)...S_m(t)$ have a bandwidth indicated at 28 in Figure 1. The spreading code signals $C_1(t)...C_n(t)$ have a bandwidth 30 which may be considerably larger than the bandwidth 28. The increased bandwidth 30 is advantageous in that it decreases noise in the transmitted and received signals and decreases the disadvantageous effects of out-of-phase signals. The out-of-phase signals are particularly disadvantageous because they can decrease the magnitude of the signals transmitted directly from the transmitter to the receiver. This results from the fact that the phases of the out-of-phase signals may be directly opposite to the phase of the directly transmitted signal. Because of this, the increased bandwidth provided by the N spreading codes facilitates the recovery at the receiver of the in-phase data provided at the transmitter and transmitted directly to the receiver. The increased bandwidth is disadvantageous in that it slows the transmission of data from the transmitter to the receiver.

As will be disclosed in detail subsequently, it is known in the prior art to change one of the data modulations and the spreading codes without simultaneously changing the other one. However, it is not known in the prior art to change simultaneously the data modulations and spreading codes. Simultaneously changing both the data modulations and the spreading codes offers certain advantages. It strengthens the signals transmitted directly from the transmitter to the receiver against fading resulting from multi-path transmissions from the transmitter to the receiver. However, there is also a disadvantage. This may be seen from the relative bandwidths of the data modulations and the spreading codes. The data modulations have a bandwidth indicated at 28 in Figure 1 and the spreading codes have a bandwidth indicated at 30. As will be seen, the bandwidth 30 is significantly greater than the bandwidth 28. The increased bandwidth 30 facilitates the recovery of the data transmitted from the transmitter directly to the receiver from the fading resulting from multi-path passages of the data from the transmitter to the receiver. However, the increased range of the bandwidth 30 slows the transmission of data from the transmitter to the receiver.

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Figure 2 schematically shows another system, primarily in block form, for sending data in a particular format from a transmitter, generally indicated at 30, to a receiver. The system 30 is designated as a single code system because there is only a single spreading code $C_1(t)$. This causes the rate of the orthogonal signals generated by the spreading code to be fixed. In this system, the number of different rates for the transmission of the data modulations is increased.

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~~The transmitter shown in Figure 2 may include a channel encoder 14a corresponding to the channel encoder 14, a mapper 16a corresponding to the mapper 16, a modulator 18a corresponding to the modulator 18 and a serial-to-digital converter 20a corresponding to the serial-to-parallel converter 20. The parallel output from the converter 20 is introduced on a bus 32 to a multiplier 34 which also receives the spreading code $C_1(t)$. The transmitter shown in Figure 2 distinguishes over the prior art in providing for simultaneous changes in the data modulations and the spreading code.~~

Figure 3 schematically illustrates a preferred embodiment of a transmitter, generally indicated at 40, of the invention. The transmitter 40 is primarily in block form and is preferred to the embodiments shown in Figures 1 and 2. The transmitter 40 includes a channel encoder 42, a mapper 44, a modulator 46 and a serial-to-parallel converter 48 respectively corresponding to the channel encoder 14, the mapper 16, the modulator 18 and the serial-to-parallel converter 20 in Figure 1.

In the system shown in Figure 3, assume that there are three (3) different data modulations and that there are five (5) different spreading codes. Under these circumstances, M would be 3 and N would be 5. The M data modulations are provided at the transmitter 40 in accordance with instructions from the receiver. In like manner, the N spreading codes are provided at the transmitter 40 in accordance with instructions from the receiver.

As shown in Figure 3, the three (3) data modulations are initially presented in a sequence as represented by the numerals 1, 2, 3 and the five (5) spreading codes are then presented in a sequence as represented by the numerals 4, 5, 6, 7, 8. The three (3) data modulations are then presented again in a sequence as represented by the numerals 9, 10, 11 and the five (5) spreading codes are again presented in a sequence as represented by the numerals 12, 13, 14, 15, 16. Successive sequences of the data modulations and then the spreading codes are repeated in the manner specified above. It will be appreciated that a sequence of the successive spreading codes may be presented before a related sequence of the successive data modulation without departing from the scope of the invention.

The successive data modulations in a sequence are introduced from the serial-to-parallel converter 48 to a bus 50. This is indicated by the numerals 1, 2, 3 in a first column, and then by the numerals 9, 10, 11 in a second column, adjacent the bus 50 in Figure 3. In like manner, the successive spreading codes in a sequence are introduced from the serial-to-parallel converter 48 to a bus 52. This is indicated by the numerals 4, 5, 6, 7, 8 below the numbers 1, 2, 3 in the first column, and then by the numerals 12, 13, 14, 15 and 16 below the numbers 9, 10, 11 in the second column.

A selector 54 is provided for selecting one (1) of the M data modulations in each data modulation sequence and a selector 56 is provided for selecting one (1) of the N different

spreading codes in each spreading code sequence. The selections by the stages 54 and 56 are paired. In other words, the M data modulations indicated as 1, 2, 3 for a time m=0 are paired with the N spreading codes indicated at 4, 5, 6, 7, 8 for a time m = 0. In like manner, the M data modulations indicated as 9, 10, 11 for a time m=1 are paired with the spreading codes indicated as 12, 13, 14, 15, 16 for the time m=1. The selections of the individual one of the M data modulations in each sequence and the individual one of the N spreading codes in each sequence may be made in accordance with instructions from the receiver. The selected one of the M data modulations in each sequence and the selected one of the N spreading codes in each sequence are combined as in a multiplier 58 and are introduced to a bus 60 for transmission to the receiver.

In the transmitter 40,

$$\log_2 M = K_m, \text{ where} \qquad (1)$$

M= a constant; and

K_m= a constant

In like manner,

$$\text{Log}_2 N = K_n, \text{ where} \qquad (2)$$

N= a constant; and

K_n= a constant

Thus $K = K_m + K_n$, where (3)

K = a constant

K indicates the number of binary bits to be provided in the encoder 42 to indicate the number of different channels to be provided for the successive stages in the transmitter.

In Figure 3, b can be considered as the output from the channel encoder 42. Successive signals representing data modulations can be represented as

$b_1(m) = [b(mk), b(mk+1)...(b\ (mk + K_m - 1)]$, where

m = a symbol time index indicated successively as 0, 1, 2, etc. (4)

b = the output from the channel encoder 42;

b_1 = the data modulations;

$b_2\ (m) = [b\ (mk + K_m), b\ (mk + K_m + 1)...b\ (mk + k - 1)]$, where (5)

b_2 = the spreading codes.

The system shown in Figure 3 has certain important advantages over the systems of the prior art and even over the systems shown in Figures 1 and 2 of this application. The system is better able to provide a distinction at the receiver between the data transmitted directly from the transmitter 40 to the receiver and phase-shifted data which limits the ability of the receiver to

detect the in-phase signals from the transmitter. The system of Figure 3 provides this distinction between the data transmitted directly to the receiver from the transmitter and the phase-shifted signals by providing M data modulations and N spreading codes. The system of Figure 3 is also advantageous over the systems of Figures 1 and 2 because it is simpler than the systems shown in Figures 1 and 2 in selecting, for combination, only an individual one of the M data modulations in each sequence and only an individual one of the N spreading codes in each sequence. The system of Figure 3 is also advantageous in that it simultaneously selects the individual one of the M data modulations in each sequence and the individual one of the N spreading codes in each sequence.

The modulated data from the transmitter is received at a preferred embodiment of a receiver generally indicated at 70 in Figure 4. The receiver 70 may be of a correlator type and is shown primarily in block form. In a correlator type, the modulated data received at the receiver is introduced to a plurality of stages and is processed in a particular manner in each of these stages. The stage with the strongest signal is presumed to indicate the modulated data transmitted from the transmitter. It provides a correlation with the transmitted signal. This signal is then processed to recover the data in the modulated data transmitted to the receiver. A receiver of the correlator type is known in the art but not in the context or environment disclosed in this application and not with the combination of stages shown in Figure 4.

The signals are received at the receiver 70 on a bus 72. The signals on the bus 72 are introduced to multipliers 74a, 74b...74n. Each of the multipliers, 74a, 74b...74n receives an individual one of a plurality of spreading code signals C_1 (t), C_2 (t)...C_n(t) respectively on lines 75a, 75b...75n. The outputs of the multipliers 74a, 74b...74n are respectively introduced to individual ones of a plurality of integrators 76a, 76b...76n. Each of the integrators 76a, 76b...76n integrates the output of its associated multiplier from the time 0 to the time T. Thus, for example,

$Z_1 = \int_o^T Q_1 \, dt$, where (6)

Q_1 = the input to the integrator 76a; and

Z_1 = the output from the integrator 76a.

In like manner,

$Z_n = \int_o^T Q_n dt$, where

where Qn = the input to the integrator 76n; and

Zn = the output of the integrator 76n.

The output from each of the integrators 76_a, 76_b...76_n is partly real and partly imaginary. To convert the output of each of the integrators, 76_a, 76_b...76_n to an entirely real number, the absolute value of each of the outputs is squared. This is indicated at 78 in Figure 4. For example, the squaring of the output from the integrator 76a may be indicated as $|Z_1|^2$ and the

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squaring of the output from the integrator 76n may be indicated as $|Z_n|^2$. A comparison is then made in a comparator 80 of the magnitudes of the different outputs from the integrators after the different integrated outputs have been squared. The individual one of the integrators 76a, 76b...76n introducing integrated output to the squaring stage 78 and providing the output with the largest magnitude in the stage 78 is then selected by a microprocessor 81 in a selector 22 on the basis of this comparison. The selected one of the integrators 76a, 76b...76n is then de-spread as at 83 to recover the modulated data. The de-spread data is then demodulated as at 84 to recover the data. The data is then analyzed on the basis of the guide lines provided by the mapper 16 and the channel encoder 14 at the transmitter to determine the significance of the data. The despreader 83 and the demodulator 84 are known in the prior art but not in the combination shown in Figure 4 and not in the context or environment set forth in this application.

A4 Cont.

Figure 5 illustrates another preferred embodiment, generally indicated at 85, of a receiver. The receiver may be of a matched filter type and is shown primarily in block form. Since the receiver 85 receives from the transmitter information concerning various parameters such as individual ones of the M data modulations and individual ones of the N spreading codes, the receiver may include a plurality of filters each having characteristics matching the characteristics of a combination of an individual one of the M data modulations and an individual one of the N spreading codes. The plurality of matched filters are indicated at 86a, 86b...86n in Figure 5 and are shown as receiving through a bus 88 the signals from the transmitter.

Each of the filters 86a, 86.....86n also receives a signal corresponding to the output capable of being provided by an individual one of the combinations of an individual one of the M data modulations and an individual one of the N spreading codes. As previously indicated, the receiver 85 knows the M data modulations and the N spreading codes since the receiver instructs the transmitter to use these data modulations and spreading codes. Because of this, each of the filters 86a, 86b...86n is able to match the characteristics of an individual one of the transmitted signals.

For example, the matched filter 86a receives signals on a line 90a. One of these signals corresponds to a combination of b(mk) and b(mk + km). The filter 86a passes the signal constituting the combination of b(mk) and b(mk + km) because of the matching characteristics of the filter with the signal provided on the line 90a. Similarly, the matched filter 86b receives signals on a line 90b. One of the signals may correspond to a combination of b (mk + 1) and b(mk + km + 1). When the signal received from the transmitter constitutes a combination of b (mk + 1) and b (mk + km + 1), the filter 86b passes the signal because of the matching characteristics of this filter with the signal provided on the line 90b. The magnitudes of the signals passing through the matched filters 86a, 86b...86n are compared in a comparator 88. A microprocessor 90 receives the signals from the comparator 88 and selects in a stage 92 the signals with the greatest magnitude from the matched filters 86a, 86b...86n. The signal passing through the selected one of the matched filters 86a....86n at each instant is despread in a

despreader 94 and demodulated in a demodulator 96 in a manner similar to that described for the embodiment shown in Figure 4.

Figure 6 shows a transmitter, generally indicated at 100, in a schematic block form. The transmitter 100 is included in a preferred embodiment of the invention. The transmitter 100 can include features of the transmitter shown in any one of Figures 1-3 and described above. The data bits are introduced through a bus 102 to an encoder 104 for encoding channels. For example, the channel encoder may provide an encoding for K channels in accordance with equation (3) set forth above. The encoder 104 may be a convolutional or turbo type of encoder. Instructions on a line 105 from the receiver shown in Figure 7 determine the encoding of the channels. A channel encoder corresponding to the channel encoder 104 is known in the prior art but not in the combination shown in Figure 6 and not for the purposes set forth in this application.

The output from the channel encoder 104 passes to a puncturer 106. A puncturer corresponding to the puncturer 106 is known in the prior art but not for purposes set forth in this application and not in the combination shown in Figure 6. The puncturer 106 deletes some of the output from the channel encoder 104 to provide for the transmission of data at an efficient and effective code rate. When the code rate of the encoder 104 is $R_c = k/n$ and l coded bits are punctured out of each (n) (P) coded bits, the effective code rate is $R_c = (KP)\ (nP\text{-}l)$. The

puncturing may be provided at the transmitter in accordance with instructions from the receiver. The instructions may be provided through a bus 108. In the above equation, K is derived from equation (3).

After puncturing, the coded bits are interleaved as at 110. Interleaving is known in the prior art. The interleaved bits are then mapped into an individual one of the modulation symbols in the selected modulation scheme. This may be provided in accordance with the system shown in Figure 3 and described above. In mapping the interleaved output bits, Gray labeling may be used. The interleaved data is then modulated as at 114. The data modulations may be provided in accordance with instructions from the receiver. The data modulations may be provided through the bus 108.

The data modulation may consist of M subsets which are orthogonal to one another and each subset may have V original points. The modulation may be selected from a number of different modes including QPSK, QAM and SQAM. The selection of the puncturing and modulation schemes is based upon the channel condition information fed back by the receiver and other sources (for example, other base stations in the cellular radio system). Each modulation symbol may be produced at a rate R_S with a period of $T_S = 1/R_s$. Each modulation may be spread by a spreader 116 such as the spreader shown in Figure 3 and described above.

The spreading may be by an orthogonal sequence of a length N_C. The spreading code may be provided through a bus 118. The output from the spreader 116 is provided on a bus 120.

Each modulation symbol may be spread by an orthogonal sequence of a length N_C. The chip rate Rchip has a fixed value (Nc)(Ks) to provide the transmitted signal with a substantially constant bandwidth. The maximum length of the spreading sequence may be denoted as Nc, max. Thus, the data rate RD is

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$$Rb = (Rce) \log_2 (LM) (Rchip)/NC$$

$$Rb = (Rcc) \log_2 (VM) Rchip/Nc)$$

The determination of the spread factor (Nc) of the spread code is based upon the delay spread observed at the receiver. (Nc) is chosen to be sufficiently large to avoid inter-symbol interference (ISI) caused by the delay spread of the multipath fading channel. As previously described, multipath fading channels occur when the data transmitted from the transmitter to the receiver also reaches the receiver through paths other than directly from the transmitter to the receiver. These indirect paths can produce inter-symbol interference (ISI) and can cause fading of the data transmitted directly from the transmitter to the receiver.

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Although the individual ones of the stages shown in Figure 6 are known in the prior art, the combination of the stages shown in Figure 6 is not believed to be known in the prior art. Furthermore, the combination of stages shown in Figure 3 and described above is not believed to

be known in the prior art. This is particularly true when the combination of stages shown in Figure is used as the modulator 114 and the spreader 116 in Figure 6. The combination of stages shown in Figures 1 and 2 can also be used as the modulator 114 and the spreader 116 in Figure 6. In addition, although the puncturer 106 and the interleaver 108 provide advantages in the construction and operation of the transmitter 100 shown in Figure 6, they can be removed from the transmitter without departing from the scope of the invention.

A Cont.

Figure 7 is a schematic block diagram of a receiver, generally indicated at 120, which can be used with the transmitter 100 shown in Figure 6. The signals received by the receiver 120 are introduced to a bus 122 which is connected to a despreader 124. The construction of a despreader such as the despreader 124 is known in the prior art but not in the combination as shown in Figure 7 and not for the purposes set forth in this application The despreader 124 eliminates the effects of the spread codes introduced to the modulated data at the transmitter such as the spreader 116 in Figure 6. The despreader 124 may operate in accordance with the instructions introduced from the receiver to the spreader 116 in Figure 6.

The signals on the bus 122 are also introduced to a channel estimator 126 which estimates the characteristics of the channel in which the signals have been transmitted to the receiver. For example, the channel estimator 126 may operate in accordance with the value K, the number of channels specified in accordance with equation (3) specified above. The signals from the

channel estimator 126 pass to lines 128 and 130. The line 128 provides the index for the spreading provided by the spreader 116 in Figure 6. The line 130 provides the index for the data modulations provided by the data modulator 114 in Figure 6.

After the received signals have been despread by the despreader 124, the modulations in the data are then removed in a demodulator 132. The demodulator 132 eliminates the modulations in the data in accordance with the instructions introduced from the receiver to the data modulator 114 in Figure 6. The demodulated data may then be introduced to a metric computer 134 which processes the data into a metric form and introduces the processed data to a deinterleaver 136.

The deinterleaver 136 restores the data to the form in which it existed before it was introduced to the puncturer 106 in Figure 6. A stage 138 designated as erasure inserter in Figure 7 restores the data to the form in which it existed before it was introduced to the puncturer 106 in Figure 6. A decoder 140 in Figure 7 restores the data to the form in which it was introduced to the channel encoder 104 in Figure 6.

Individual ones of the despreader 124, the demodulator 132, the metric computer 134, the deinterleaver 136, the erasure insertion stage 138 and the decoder 140 are known in the prior art but the combination shown in Figure 7 is not believed to be known in the prior art. Furthermore,

the combination is not known in the prior art for the purposes set forth in this application When the puncturer 106 and/or the interleaver 108 are not included in the transmitter shown in Figure 6, the deinterleaver 136 and/or the erasure insertion stage 138 will not be included in the receiver shown in Figure 7.

Assume that a block or packet of data spans a time duration of T_B and that the block or packet of data is transmitted by the transmitter 100 to the receiver 120 at successive instants of time. Assume also that the time interval between consecutive transmitted blocks or packets is T_{FD}. The time interval T_{FD} may correspond to the delay in the feedback from the receiver 120 to the transmitter 100 of information relating to the channel conditions. As previously indicated, the signal received by the receiver 120 from the transmitter 100 are processed to decode the transmitted data bits and recover the transmitted data. The received signal is also used to estimate the local average of the channel conditions. The term "local average" is intended to mean that averaging is provided over the time span of T_B, the duration of a block or packet of data.

The relative speed between the movements of the transmitter 100 and the receiver 120 helps to determine the dynamics of the channel conditions. At a low speed of relative movements between the transmitter 100 and the receiver 120, the channel condition can be almost constant over a time duration of T_B or even over a multiple number of time durations of

T_B. At a high speed of relative movements between the transmitter 100 and the receiver 120, the channel condition can fluctuate many times over a wide range of values over the same time period of T_B or a multiple number of time durations of T_B.

The characteristics of the time-varying multipath fading channels include the local average of signal-to-noise ratio (SNR), where noise represents all of the components other than the desired signal, delay spread and variability of the desired signal amplitude level among other things. The amount of the delay spread determines the level of inter-symbol interference (ISI) and cross interference between the transmitted orthogonal signal components. In the preferred embodiments of this invention, increasing the spreading factor can reduce the level of the inter-symbol interference (ISI). Furthermore, it also enhances the capability of suppressing interference of the transmitted spread spectrum signal and helps to maintain the orthogonality between the transmitted signals. It also has an effect of lengthening the duration of the modulation symbols. Spreading factor can be defined as the ratio between the chip rate of the spreading codes and the rate of the data modulations.

Thus, depending upon the level of the delay spread observed in the spreading codes, the spreading factor is selected to provide sufficient protection against the inter-symbol interference (ISI) and against the cross interference. This will simplify the processing complexity of the receiver signal by avoiding equalization or other techniques of interference suppression.

Assuming that the spreading factor selected is sufficiently large to suppress the delay spread efforts of the multipath fading channel, the channel characteristic observed at the receiver 120 after despreading can be modeled by a flat fading channel. The performance at the receiver will accordingly depend upon the local average signal-to-noise ratio (SNR) and the variance of the desired signal level. The optimal combination of code rate (or puncturing) and the scheme of the data modulations is determined based upon the two (2) aspects of the channel characteristics.

This invention provides for a combination of a channel code rate, data modulation and spreading code. This combination is provided to enhance the spectral efficiency achievable even with the deteriorations resulting from multipath fading channels. A set of orthogonal spreading sequences may be used for spreading, and a determination of the spreading factor (or processing gain) is made based upon the channel impulse response to provide sufficient protection against the channel effects, such as delay spread, of multipath fading.

Different channel code rates may be obtained by puncturing simple basic convolutional or turbo code so that a single decoder can be used for different combinations of code rate and data modulation. After selecting the spreading factor, channel code rate and data modulation are determined based on local average channel conditions instead of instantaneous channel conditions. Then the number of orthogonal spreading sequences is determined based on the user's data rate specification.

By selecting spreading factor, code rate and data modulation, targeted data rate can be achieved by using a minimal amount of radio resources under time-varying channel conditions. In adapting spreading factor, code rate and data modulation, it is important to realize that feedback delay in having the receiver inform the transmitter of channel conditions will be unavoidable. Because of this, it is important to realize that adaption by the system shown in Figures 6 and 7 should be based upon local average channel conditions. This provides for a successful adaptation by the system shown in Figures 6 and 7. It should also be appreciated that the system should also be based upon local average channel conditions when the transmitter 100 shown in Figure 6 is adapted to incorporate any of the systems shown in Figures 1-3 and/or when the receiver 120 shown in Figure 2 is adapted to incorporate either of the systems shown in Figures 4 and 5.

Solely relying on either one of the two (2) techniques of data modulation and spreading code to provide communication services at high data rates will cause the system to be inefficient or make the modem implementation inordinately complicated. By combining channel encoding, direct sequence spreading and adaptive coded modulation, high data rate wireless communication services can be provided reliably and efficiently.

Although this invention has been disclosed and illustrated with reference to particular embodiments, the principles involved are susceptible for use in numerous other embodiments

which will be apparent to persons of ordinary skill in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.